



# The effect of self-producing heat and external radiation on the insulating property of wire

Jin-mei Li<sup>a,b</sup>, Qiang Li<sup>b,\*</sup>, Zhong-jun Shu<sup>b</sup>, Jia-qing Zhang<sup>c</sup>, Ming-hao Fan<sup>c</sup>

<sup>a</sup> University of Science and Technology Beijing, Xueyuan Road 30, Beijing 100083, China

<sup>b</sup> Chinese People's Armed Police Forced Academy, Xichang Road 220, Langfang 065000, China

<sup>c</sup> State Grid Anhui Electric Power Research Institute, Jinzhai Road 79, Hefei 230026, China

## Abstract

The effect of self-producing heat and external radiation on the insulating property of wire are studied experimentally in this paper. In the experiments of self-producing heat of wire, 6 types of wires are used under the situation of overloading. The results show that the effect of the temperature rise of wire on insulating property of wire is remarkable. Under the situation of having electric current wired to produce heat by itself, the insulation resistance of wire decreases and the leakage of electricity electric current enhances. Under the situation that electric current is relatively stable, the temperature becomes stable when rising to a certain value, conducting wire heat dissipating and fever heat are in an equilibrium state. In the experiments of external radiation, such as the situation of building fire, RV sheathed wires present a similar regulation to the self-producing heat experiments. The difference is that the effect of external factor (such as air flow, voltaic instability, etc.) on temperature of wire is more obvious than that on the insulation resistance of wire. When external factor makes the wire temperature decrease to a certain value, the insulation resistance value is higher than that out of the effect.

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Peer-review under responsibility of the organizing committee of ICPFFPE 2015

**Keywords:** insulating property, temperature, overloading, external radiation.

## Nomenclature

$I$	current (A)
$R$	insulation resistance ( $\Omega$ )
$U$	voltage (V)

## 1. Introduction

Stream conductor insulator will be aging to different degrees after running for some time, because it can be affected by the surroundings. This situation is much common in the old streets of the towns and the old companies, particularly in shanty town. In order to solve the problem that the number of fire caused by that is increasing, researches on stream conductor insulator are more and more popular at home and abroad in recent years [1]. Research achievements are continuously applied in the production of electric wires and in the process of using electric wires. For instance, Restored Voltage Method [2-4] is invented by a foreign research institutions. The method provides a new way to test insulation, which overcomes the defects of testing inconvenience, inaccuracy and bad effects from electromagnetic field. In China,

\* Corresponding author. Tel.: +86-316-206-8522; fax: +86-316-206-8508.  
E-mail address: [sterops@foxmail.com](mailto:sterops@foxmail.com)

*Cable Material Research Center in Harbin University of Science and Technology* studies the effects of producing heat on the extrusion swelling ratio and the effects of the ratio on the insulation, focusing on the extrusion swelling. What's more, they find out several ways of reducing the extrusion swelling ratio to improve the capability of insulation of wires and cables [5, 6].

As the capability indicator of stream insulator, the insulation resistance is not a stable number. There are many factors, among which the temperature has much more influence. The research is to analyze the effects of electric current and outside radiant heat on the stream conductor insulation resistance and the effects of heat on the stream conductor insulation, in order to provide data to study the factors of influencing the stream conductor insulation.

## 2. Experiment Instruments

### 2.1. EST 121 digital high electric resistance and micro current tester

EST121 digital high electric resistance and micro current tester, produced by *Beijing Hua Jing Hui Technology and Business Company*, is used to measure electric current and micro current. The testing range of electric resistance is  $1 \times 10^4 \sim 1 \times 10^{18} \Omega$  and divided into ten ranges. The testing range of electric current is  $2 \times 10^{-4} \sim 1 \times 10^{-16} \text{ A}$ . The operating voltages are DC 10 V, 50 V, 100 V, 250 V, 500 V and 1000 V.

Compared with common Megger, EST121 can test the voltage ( $U$ ) in both ends of electric resistance and the current of the electric resistance ( $I$ ) at the same time, through the inside LSI (Large Scale Integrated circuit) to finish the calculation by Ohm's law, and then the result will be converted by A/D to show the resistance value. Even if the voltage in both ends of electric resistance and the current of the electric resistance are changed at the same time, the resistance value will not change like common Megger. So, even if the influence from the change in the voltage, resistance and supply voltage is not great, the accuracy is good. The error can be zero theoretically while the actual error can be ppm level.

The insulation resistance value of insulation material is measured in the experiment. Because the insulation resistance value of PVC is quite high, the measured value can be easily affected by the surrounding electromagnetic field. The shielding measure should be adopted in the tests to avoid that the measured value is not stable and even not readable. Three-electrode is used in the test. It can be connected following the advice of Figure 1.

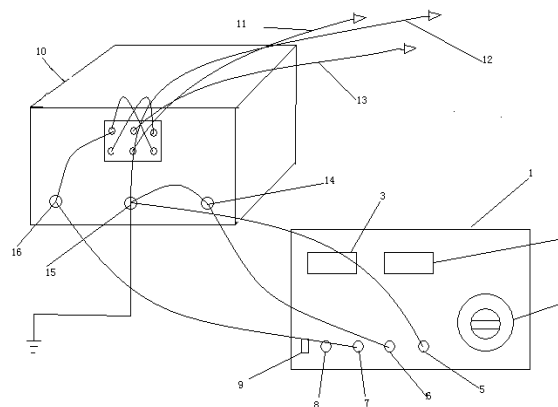


Fig. 1. The Diagram of EST121 Digital High Electric Resistance and Micro Current Tester.

- |                                    |                         |                             |                                  |
|------------------------------------|-------------------------|-----------------------------|----------------------------------|
| 1. EST121 Tester                   | 5. current binding post | 9. power switch             | 13. high voltage output terminal |
| 2. high electric resistance screen | 6. earth binding post   | 10. shielding box           | 14. earth binding post           |
| 3. micro current screen            | 7. voltage binding post | 11. shielding line          | 15. current binding post         |
| 4. range switch                    | 8. zeroing switch       | 12. current output terminal | 16. voltage binding post         |

### 2.2. IRI 1010 thermal imager

The temperature is measured by IRI 1010 thermal imager from *Britain IRISYS Company*. The testing range of the temperature is  $-10 \sim 300^\circ \text{C}$ , FOV (Field of View) is  $20^\circ \times 20^\circ$ , spectrum from 8 m to  $14 \times 10^{-6} \text{ m}$ , the distance of temperature

test from 0.7 m to infinite far and laser positioning. Laser positioning built-in the laser of level 2, which can send reference points to help user position the abnormal temperature. The surroundings temperature:  $-5\sim 70^{\circ}\text{C}$ .

### 2.3. Wires

Seven types of wires are used in experiments, as is shown in Table 1.

Table 1. Wire types and sizes

Types	Core of conductor	Cross section ( $\text{mm}^2$ )	Current-carrying capacity, $I_e$ (A)
BV	single	1.5	22
		2.5	31
RV	single	1.5	23
		2.5	31
BLV	single	1.5	18
		2.5	31
RV sheathed wire	multicore	1.5	23

## 3. Self-producing heat under the situation of overloading

### 3.1. Experimental setup

In this experiment, the wires are BV wire (cross section:  $1.5\text{ mm}^2$ ,  $2.5\text{ mm}^2$ ), RV wire (cross section:  $1.5\text{ mm}^2$ ,  $2.5\text{ mm}^2$ ), BLV wire (cross section:  $1.5\text{ mm}^2$ ,  $2.5\text{ mm}^2$ ), as is shown in Table 1. The chosen wire is 1m long. The middle part of the insulator is cut by 2~3 cm to expose the core. Then both ends of the wire are connected with the output terminals of AC Current Booster KSL-500.

KSL-500 AC current booster is provided by *Tianjin Xinhua electric device Ltd.* The device uses the method of electromagnetic induction (see Figure 2). The rated capacity: 2.5 kW, alternating current: 0~500 A, rated output voltage: 0~5 V, dielectric strength: 2500 V/min, insulation resistance:  $>2500\text{ M}\Omega$ , temperature:  $-20\sim 45^{\circ}\text{C}$ , relative humidity:  $< 80\%$ .

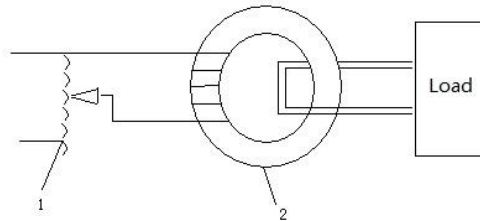


Fig. 2. Schematic of KSL-500 AC Current Booster.

Turn the range switch to minimum and then turn on the power. Follow Figure 1 to connect shielding box and digital high resistance and micro current tester EST 121. Turn on the power. Use the clamp of shielding line next to the exposed core and the clamp of current output terminal 5cm distant to the clamp of shielding line. Adjust the KSL-500 range switch to be  $1I_e$  (current-carrying capacity). Put the lens of thermal imager in 70 cm between the two clamps, laser positioning points to the line and turn on the stopwatch at the same time. Write down the insulation resistance value and temperature every one minute. In the way, study the change of stream conductor's temperature on insulation under the condition of  $1I_e$ ,  $1.5I_e$ ,  $2I_e$  and  $3I_e$ . Write down the curve of time-temperature and time-insulation resistance.

### 3.2. Experimental Phenomenon

Insert the wire to the output terminal of the AC Current Booster, and study the phenomenon of the 6 different types of wires when having the  $3I_e$  running through. Record the relevant data during the experiment, as it shows in Table 2.

Table 2. Experimental phenomenon of wire when having the 3 times current-carrying capacity

Type of wire	Cross Section (mm <sup>2</sup> )	Smoking		Swelling		Max temperature (°C)
		Temperature (°C)	Time (min)	Temperature (°C)	Time (min)	
BV	1.5	41	4	56	5	61
	2.5	44	3	63	4	78
BLV	1.5	40	5	54	6	68
	2.5	40	4	59	5	79
RV	1.5	39	2	57	2.5	103
	2.5	39	1.5	57	2	104

In the experiment about the single wire under the situation of having electric current running through, 3 of the wires smoke when the temperature comes around 40 °C; under the same current grade the BLV smoke for the longest time, followed by BV wire, and RV wire is the first one that comes to smoke; the wires begin to swell while the temperature gets around 60 °C; and the comparison for swelling time is: BLV wire > BV wire > RV wire; under the  $3I_e$ , the maximal temperature of RV wire is highest, and the maximal temperature of BLV and BV wires are much the same; when comparing to wires made of the same material, those with smaller cross section have a lower temperature when they smoke and swell, as well as a lower maximal temperature than those with larger cross section. And the wires with larger cross section smoke and swell earlier than those small ones.

### 3.3. Result and analysis

The time-temperature curve and time-insulation resistance curve during experiment, as it is shown in Figure 3 to Figure 7.

According to the electric heating theory, heating will wire to the decline of insulation capability of wire. It can be seen from Figure 3 that, during the whole experiment, the temperature value and insulation resistance value keep changing. While the temperature rises, insulation resistance value decreases and the leakage of electric current enhances correspondingly, which conforms to the theory. At the beginning of the experiment, when the temperature rises sharply, the insulation resistance value declines immediately and changes largely. Then the changes become small and insulation resistance value changes correspondingly in a narrow range; in the end, the temperature and insulation resistance value will have certain vibration, but the temperature vibration will be larger than that of insulation resistance value. According to the past theory, temperature value will keep increasing, while the insulation resistance value keeps decreasing, and finally both of them will reach a constant value. The reasons for transformation are: the electric current running through the wires provided by KSL-500 AC Current Booster is not constant, but ever-changing, and back-flow is found after just several minutes or dozens of minutes; besides, the same type of wires will have different constant values for temperature and insulation resistance when they are under different current rating. When the current rating becomes higher, the constant temperature will be higher while the constant value of insulation resistance will be lower.

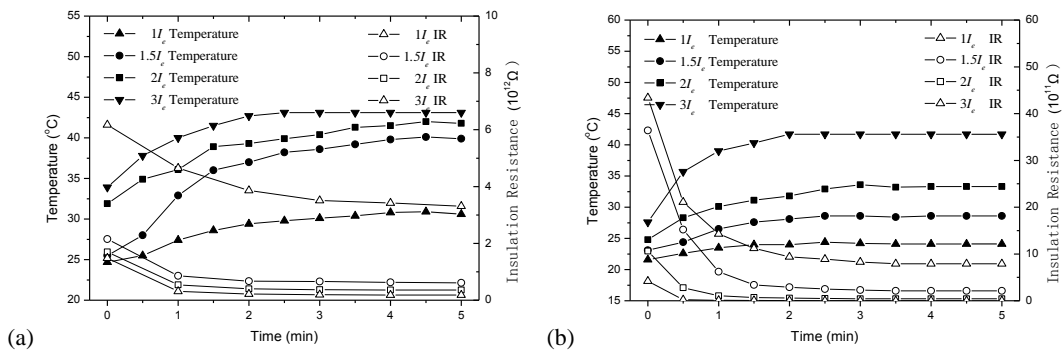


Fig. 3. Time-insulation resistance curve under the situation of self-producing heat of wires for (a) 1.5 mm<sup>2</sup> BV and (b) 2.5 mm<sup>2</sup> BV.

In the experiment about overcurrent running through 2.5 mm<sup>2</sup> BV wires, as is shown in Figure 3(b), when the temperature rises, the insulation resistance value keeps decreasing; when having  $3I_e$  running through the wire, the changing range of temperature will be larger than that of those having other ratings of current running through. What's more, in the 2.5th minute, the clamp in the current output terminal will penetrate the insulator, which will be softened with the rising temperature, to the core of wire, at this time the insulation resistance value will be 0  $\Omega$  and the temperature will reach 32.9  $^{\circ}\text{C}$ .

Since the insulation materials on the market are incomplete, the resistance abilities to breakdown of the insulation materials differ from each other, which becomes one of the important reasons for current-leakage fires even though when using the wire in the normal way.

In the experiment about electric current running through 1.5 mm<sup>2</sup> BLV wires, we can see from Figure 4(a) that, when the temperature rises, the insulation resistance value keeps decreasing; when having  $3I_e$  running through the wires, the changing range of temperature will be larger than that of those wires having other ratings of current running through.

In the experiment about electric current running through 2.5 mm<sup>2</sup> BLV wires, we can see from Figure 4(b) that, when the temperature drops down, the insulation resistance value will keep decreasing; when having  $3I_e$  running through the wires, the changing range of temperature and insulation resistance value will be larger than those of wires having other ratings of current running through. What's more, in the fifth minute, the clamp penetrates the insulator and meets the core of wire, at this time the insulation resistance value is 0  $\Omega$  and the temperature reaches 42  $^{\circ}\text{C}$ .

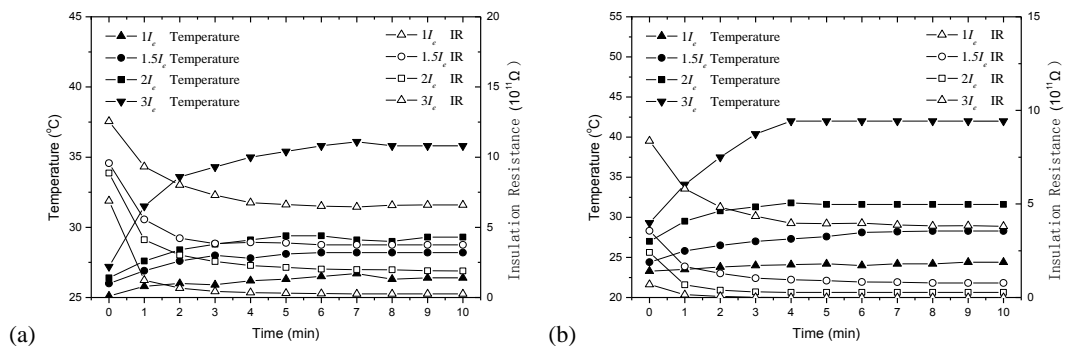


Fig. 4. Time-insulation resistance curve under the situation of self-producing heat of wires for (a) 1.5 mm<sup>2</sup> BLV and (b) 2.5 mm<sup>2</sup> BLV.

In the experiment about electric current running through 1.5 mm<sup>2</sup> RV wires, we can see from Figure 5(a) that, when the temperature drops down, the insulation resistance value will keep decreasing; when compared with BV wires and BLV wires, within the same period, the changing range of temperature and insulation resistance value for RV wires is larger; when having  $3I_e$  running through the wires, in the second minute, the insulation resistance value is 0  $\Omega$  and the temperature reaches 42.7  $^{\circ}\text{C}$ .

In the experiment about electric current running through 1.5 mm<sup>2</sup> RV wires, we can see from Figure 5(b) that, when the temperature drops down, the insulation resistance value will keep decreasing; when having  $3I_e$  running through the wires, in the second minute, the insulation resistance value is 0  $\Omega$  and the temperature reaches 47.6  $^{\circ}\text{C}$ .

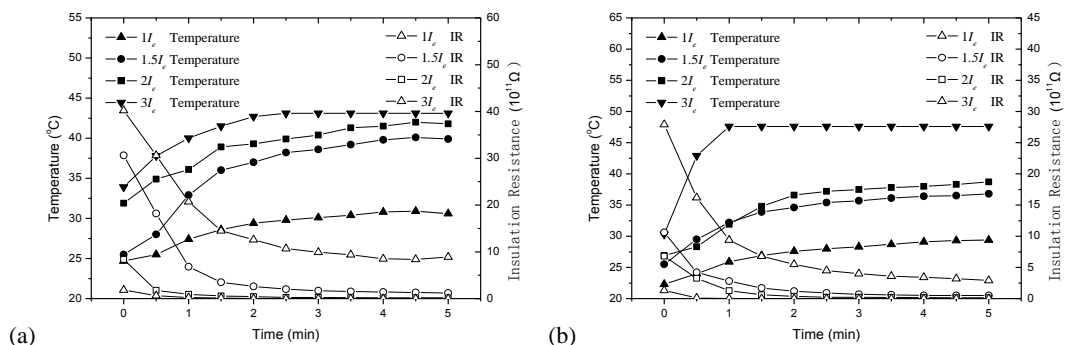


Fig. 5. Time-insulation resistance curve under the situation of self-producing heat of wires for (a) 1.5 mm<sup>2</sup> RV and (b) 2.5 mm<sup>2</sup> RV.

#### 4. External radiation under the situation of flashover

##### 4.1. Experimental setup

RV sheathed wire is used in the experiment, as is shown in Table 1. The chosen wire is 1m long. The adjustable electric furnace produced by *Beijing Guangming Company* is used as the external radiation heat source. The radiant surface of electric furnace is a square with a length 18 cm.

Bake the wire with the adjustable electric furnace. Simulate the situation of thermal radiation flashover in building fires. Study the effects of radiant heat on insulating property of wire. The diagram of the experiment is shown in Figure 6(a). Connect the core of wire with EST 121 as shown in Figure 6(b).

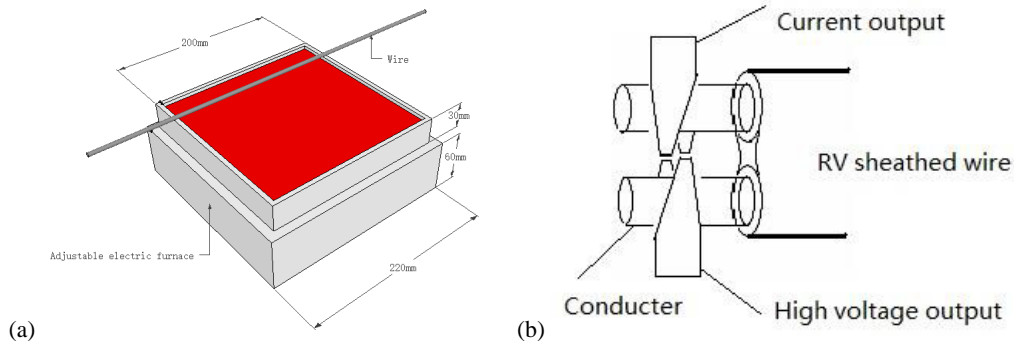


Fig. 6. Diagram of the experiments for (a) installation of electric cooker and wire and (b) connect the core of wire with EST 121.

Sustain the sheathed wire and the connection of shielding box and Megger. Connect electric cooker and strong current generator. Turn on the power of strong current generator. Put RVV above 10 cm of the fuse of electric cooker. Put both clamps of current output terminal and high voltage output terminal on the cores respectively.

Heat flux in this experiment are 25 kW/m<sup>2</sup>, 35 kW/m<sup>2</sup>, 45 kW/m<sup>2</sup>. According to

$$qs = UI$$

Where  $q$  is heat flux, kW/m<sup>2</sup>;  $s$  is the surface area of heat dissipation from the inscribed circle of electric cooker, m<sup>2</sup>;  $U$  is the power voltage, V;  $I$  is current of strong current generator, A. So, when  $q = 25$  kW/m<sup>2</sup>,  $U = 220$  V and  $s = 3.14 \times 0.092^2 = 2.5 \times 10^{-2}$  m<sup>2</sup>, then  $I = 2.8$  A.

Adjust the range switch of strong current generator to make the figure of clamp-on ammeter to be 2.8 A and the output resistance value of the generator  $U = 130$  V. Connect electric cooker and the generator and place the wires, study the changes of temperature on wire insulation when heat flux is 25 kW/m<sup>2</sup>.

In the above way, study the influence of the changes of temperature on wire insulation under the condition of  $q = 35$  kW/m<sup>2</sup>, 45 kW/m<sup>2</sup> when the wire is affected by thermal radiation. So, when  $I = 4$  A, then  $U = 165$  V and when  $I = 5.1$  A then  $U = 185$  V.

##### 4.2. Result and analysis

Time-temperature curve and time-insulation resistance changing curve during experiment, is shown in Figure 7.

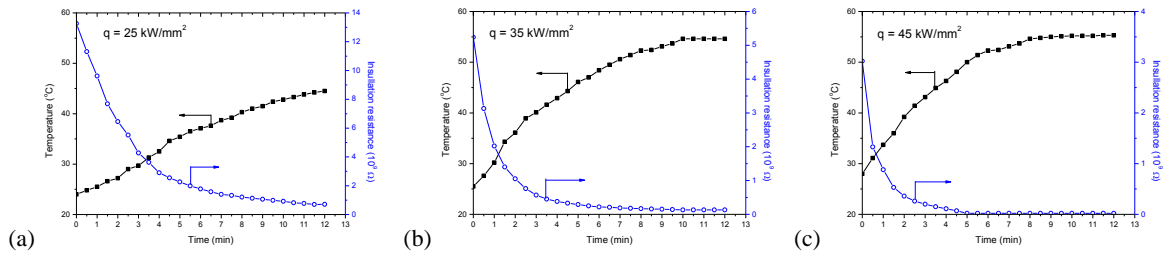


Fig. 7. 1.5mm<sup>2</sup> RV sheathed wire time-temperature curves under the situation of external radiation for (a) 25 kW/m<sup>2</sup>, (b) 35 kW/m<sup>2</sup> and (c) 45 kW/m<sup>2</sup>.

In the experiment about the effects of the flashover temperature on the insulation capability of 1.5 mm<sup>2</sup> RV sheathed wire's insulator, we can see from Figure 7 that, when there is no electric current running through the wires, the temperature rises, the insulation resistance value will decrease, that is, the insulation capability decreases, which conforms to the rules of stream conductors; when the heat flux keeps increasing, the changing ranges for temperature and insulation resistance value will become larger; when compared with BV wires, BLV wires and RV wires, the insulation resistance of the sheathed wire is correspondingly smaller, and the insulation capability is also poorer. In the experiments under the situation of  $q=35$  kW/m<sup>2</sup> and  $q=45$  kW/m<sup>2</sup>, the changes of experimental data curve shows no significant differences, but the differences are much larger when compared with the changes of the curve when  $q=25$  kW/m<sup>2</sup>; when the heat flux keeps increasing, the risks generated by the current leakage of the wire itself will be higher. In the experiments under the situation of  $q=35$  kW/m<sup>2</sup> and  $q=45$  kW/m<sup>2</sup>, the insulation resistance value will be around 0 Ω in the fifth and third minute respectively.

## 5. Conclusions

(1) When there is electric current running through the wires, the temperature will have big effects on the insulation capability of the wire insulator. When the temperature rises, the insulation resistance value decreases, current leakage increases correspondingly; when the temperature drops down, the insulation resistance value increases, current leakage decreases correspondingly.

(2) When cutting off the electricity and the running electric current is under a certain value, the wire temperature will drop down to ambient temperature slowly, and the insulation resistance value will basically return to the resistance value which is in no-electricity condition.

(3) Under the same temperature, the insulation resistance value of 1.5 mm<sup>2</sup> RV sheathed wire is smaller than that of the 1.5 mm<sup>2</sup> RV wire, and the risks for current-leakage fires are higher.

(4) The radiant heat experiment, we can also find out the discipline concluded from (1). That is, whether there is electric current running through the wires. If the temperature rises, the insulation resistance value decreases, current leakage increases correspondingly; if the temperature drops down, the insulation resistance value increases, current leakage decreases correspondingly.

(5) Under the situation of having the same rating of current running through the wires, RV wires, when compared with BV wires and BLV wires, are more easily to release heat, its temperature rises more rapidly, the maximal temperature is higher and it is more likely to cause fires.

(6) Under the situation of having the same rating of current running through the wires of the same type and materials, the wires with larger cross section are more likely to smoke, swell and cause fires.

## Acknowledgements

This work was sponsored by the Hebei Province Natural Science Foundation of China, Project No. E2013507011, the Open Foundation of Ministry of Public Security Key Laboratory of Fire Fighting and Rescue Technology, Project No. KF2013006 and Anhui Provincial Natural Science Foundation of China, Project No. 1408085MKL94. We are sincerely grateful to Ze-xun ZEN for the correction of grammatical mistake in the paper.

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Jin-mei LI, female, born in Anshun city, Guizhou province, in 1980. Graduated from the State Key Laboratory of Fire Science (SKLFS) of University of Science and Technology of China (USTC) with Master Degree in Safety Science and Engineering. At present employment in Department of Fire Protection Engineering of Chinese People's Armed Police Forced Academy as a lecturer. Li's research field include fire science and fire protection engineering, methods and tools of performance-based fire protection design, and codes of design and technical standards.



Qiang LI, male, born in Jilin city, Jilin province, in 1979. Graduated from the State Key Laboratory of Fire Science (SKLFS) of University of Science and Technology of China (USTC) with Doctor Degree in Safety Science and Engineering. At present employment in Department of Fire Protection Engineering of Chinese People's Armed Police Forced Academy as an associate professor. Li's research field include electrical fire safety technology, fire detection technology, and enclosure fire dynamics.



Jia-qing ZHANG, male, born in Anqing City, Anhui province, in 1987. Graduated from University of Science and Technology of China (USTC) with PhD in Safety Science and Engineering, and from City University of Hong Kong (CityU HK) with PhD in Architecture and Civil Engineering. At present employment in State Grid Anhui Electric Power Research Institute as a research engineer. Dr Zhang's research interests include electric fire and safety protection, fire safety issues in energy utilization, etc. He has published over 30 refereed journal and conference papers.



Ming-hao FAN, male, born in Heifei City, Anhui province, in 1975. Graduated from Zhejiang University with PhD in Mechanical electronic control engineering. At present employment in State Grid Anhui Electric Power Research Institute as a senior engineer. Dr Fan's research interests include electric fire and safety protection, features of SF6 and the management of its safe operation, etc.

